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## **Establishing Native Submersed Aquatic Plant Communities in Southern Reservoirs**

by *R. Michael Smart, Robert D. Doyle, John D. Madsen, WES  
Gary O. Dick, AScl Corporation*

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by **R. Michael Smart, Robert D. Doyle, John D. Madsen**

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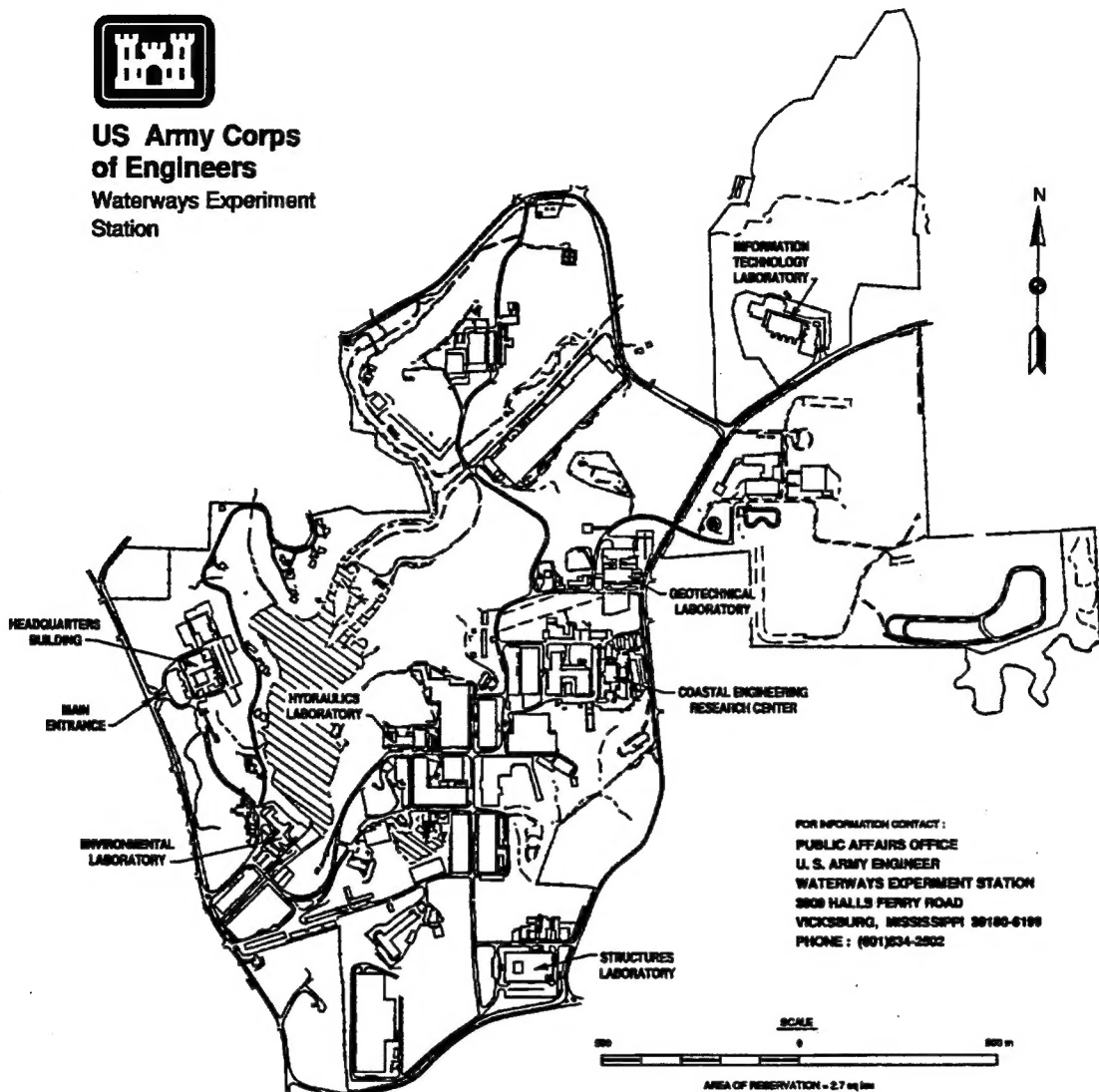
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# Contents

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Preface .....	iv
Conversion Factors, Non-SI to SI Units of Measurement .....	vi
1—Introduction .....	1
2—Why Reservoirs Need Establishment of Aquatic Plants .....	4
3—Species Selection .....	6
Life History Considerations .....	7
Plants to Avoid .....	7
Native Plants to Consider .....	9
4—Project Implementation .....	12
Propagule Acquisition .....	12
Establishment in the Field .....	15
5—Reviews of Recent Establishment Efforts .....	21
Annuals .....	22
Tuber-Forming Perennials .....	23
Other Perennials .....	25
6—Conclusions .....	27
References .....	28
Appendix A: Line-Intercept Transect Method .....	A1
SF 298	

# Preface

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The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32577. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Program Manager. Mr. Robert C. Gunkel, Jr., was Assistant Manager, ERRAP, for the APCRP. Program Monitor during this study was Ms. Denise White, HQUSACE.

Principal Investigator for this study was Dr. R. Michael Smart, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), WES. The report was prepared by Dr. Robert D. Doyle, assigned to the EPED under an Intergovernmental Personnel Act Agreement (IPA) with the Institute of Applied Science, University of North Texas, Denton, TX, with contributions from Drs. Smart and John D. Madsen, Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX, and Dr. Gary O. Dick, AScl, Vicksburg, MS. The report was reviewed by Dr. Susan Sprecher and Mr. Mike Stewart, EPED.

This investigation was performed under the general supervision of Dr. Richard E. Price, Chief, EPEB, Mr. Donald L. Robey, Chief, EPED, and Dr. John W. Keeley, Director, EL.

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# Conversion Factors, Non-SI to SI Units of Measurement

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Non SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.489	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers



# 1 Introduction

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Some reservoirs appear to remain turbid and unvegetated for many years, while others develop extensive macrophyte communities and are much clearer. In fact, ecological theory has long recognized the possibility that ecosystems may have multiple stable equilibria that might diverge drastically from each other (May 1977). Aquatic environments with intermediate nutrient inputs appear to have two stable equilibrium states: a clear state characterized by transparent water and an abundance of aquatic macrophytes, and an alternative turbid state characterized by high turbidity (plankton and resuspended sediments) and a virtual absence of aquatic macrophytes (Scheffer 1990; Scheffer et al. 1993).

While some species of submersed aquatic plants cause serious management problems, most species contribute significantly to the aquatic environment by stabilizing the sediments and improving water clarity (Carpenter and Lodge 1986), taking up nutrients from the water (Kufel and Ozimek 1994) and providing quality habitat for fish (Engel 1985; French 1988; Killgore, Morgan, and Rybicki 1989). In addition, some native species are highly competitive and may offer protection from invasion by nuisance exotic species (McCreary, McFarland, and Barko 1991; Smart, Barko, and McFarland 1994).

Beneficial submersed aquatic plant communities typically have low to moderate levels of biomass production, a high diversity of species that provide structurally diverse habitats, and are dominated by growth forms that concentrate biomass below the surface of the water (Figure 1A). These communities provide both desirable aquatic habitat and water quality benefits. Temperature and oxygen distribution within these communities are excellent throughout the diurnal cycle (Honnell, Madsen, and Smart 1993).

While a diverse native aquatic plant community is a desirable feature of the aquatic ecosystem, excessive growths of submersed aquatic plants can cause serious and costly management problems and interfere with continued use of the water resource for project objectives. Problems typically occur when extensive populations develop very high levels of biomass and have a growth form that produces a dense canopy of vegetation at the air:water interface (Figure 1B). When such populations grow in strategic or high-use locations like boat ramps, channels, water intakes, or swimming areas, there is an immediate management problem. Under these conditions, the beneficial

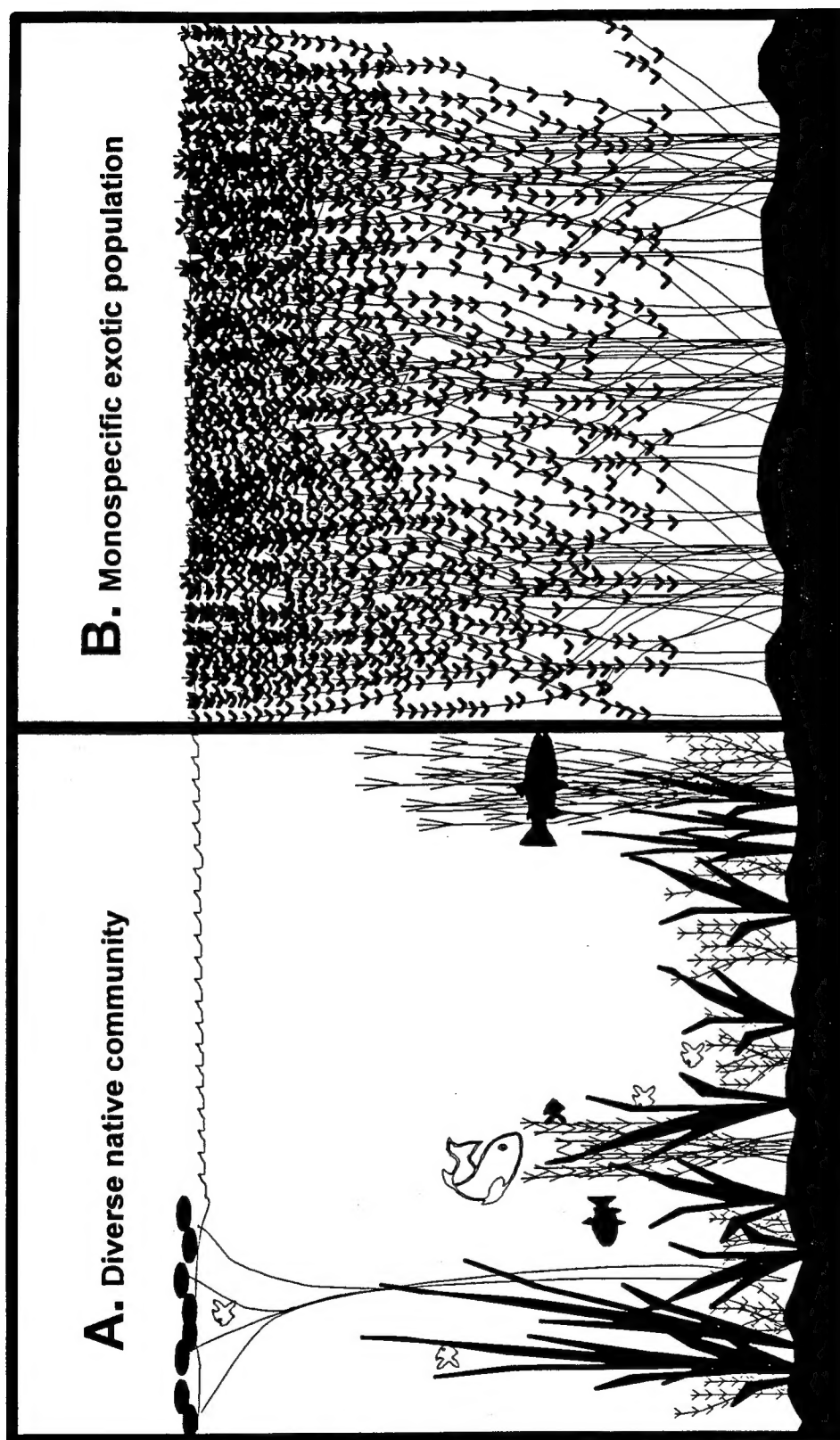


Figure 1. Submersed aquatic plant communities

aspects of having plants in the aquatic environment are outweighed by numerous management problems such as interference with recreation, navigation, water supply and hydropower generation, or by the plants physically impeding access to the water.

This report will (a) review why plant establishment efforts are needed in man-made reservoirs, (b) identify plants appropriate for establishment in reservoirs, and (c) identify important considerations for plant establishment efforts, including propagule acquisition and methods for establishment in the field. In many cases, it may also be desirable to promote the establishment of emergent macrophytes. While beyond the scope of this report, information on establishing emergent plants is available from various sources (Hammer 1992; Doyle and Smart 1993).

## 2 Why Reservoirs Need Establishment of Aquatic Plants

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Two major factors appear to be primarily responsible for maintaining unvegetated reservoirs in that state. First, reservoirs are man-made systems and do not rapidly develop into complex ecosystems on their own. At construction, new reservoirs usually encompass large areas of potential aquatic plant habitat, but have little or no aquatic vegetation to occupy these areas. Whereas plant communities in natural lakes have developed over hundreds of years of ecological interactions, plant communities in even the oldest reservoirs are very young in an ecological sense (Godshalk and Barko 1985); reservoirs should not be expected to spontaneously develop desirable aquatic plant communities, particularly in the absence of local native plant communities to provide propagules.

The second reason reservoirs may remain unvegetated is that new reservoirs are not hospitable environments for establishment of most submersed aquatic plants, particularly if these newly arriving species are introduced as seed or small shoot fragments. Since many reservoirs are operated for flood control or water supply, their water levels may fluctuate over broad ranges. While many species of aquatic plants are adapted to natural hydrologic cycles, water level fluctuations in reservoirs may be out of synchrony with seasonal weather cycles. Excessive inorganic turbidity or excessive algal or epiphyte growth reduces light levels available to establishing plants, making it difficult for small plants to receive adequate light for photosynthesis and growth. Also, since bottom substrates of new reservoirs are merely flooded terrestrial soils, these may not be initially suitable for the growth of rooted aquatic plants, particularly if soils are rocky or hard-packed clay. Finally, herbivores in the reservoir may prevent establishment of submersed plants by exerting intense feeding pressure on small populations of relatively fragile, immature plants.

These two factors of few plant propagules and unfavorable environmental conditions within man-made reservoirs likely act in concert to impede the establishment of submersed vegetation in many reservoirs. Even so, given enough time, reservoirs may develop a submersed aquatic flora. However, this process can take many years, and, left to chance, the resultant plant community may not be desirable. Exotic weedy species such as hydrilla are

highly adapted for colonizing disturbed sites and often arrive and establish prior to the development of native plant communities.

For purposes of discussion, there are four situations where establishment of aquatic plant communities are considered to be desirable:

- a. Reservoirs with little or no existing aquatic vegetation.
- b. Reservoirs with a limited distribution of only a few pioneer species.
- c. Reservoirs infested with undesirable exotic species.
- d. Reservoirs with diverse and desirable aquatic plant communities.

Since completely unvegetated reservoirs are generally inhospitable to seedling establishment, management intervention may be required in order to break the turbidity cycle and begin to move the system towards the vegetated, clear state. Plantings of desirable native aquatic plant species may initiate this process. The concept of "stocking" desirable organisms to manipulate the species composition of freshwater ecosystems is not new since fisheries managers have for decades stocked desirable fish into reservoirs. Often, surveys of fish communities are performed periodically, and additional stockings are made to achieve and maintain desired fish communities. This practice should be extended to the management of aquatic plant communities, which are an important component of the ecosystem on which the fish depend.

Reservoirs with a limited distribution of only a few pioneer species will require active management to increase both the areal extent and species diversity of the plant community. A diverse plant community will provide a more heterogeneous habitat, increasing the number of food items for fish (Butler et al. 1992; Schramm and Jirka 1989) and adding stability to the reservoir ecosystem (Scheffer et al. 1993).

Reservoirs infested with undesirable exotic species will pose particularly difficult challenges. Restoration of these ecosystems will require that managers take prompt and aggressive action to control the nuisance plants and replace them with more useful species. Successful restoration will likely require integration of many aquatic plant management tools, including selective chemical control, biological control, mechanical control, and drawdowns, coupled with a native plant stocking program to encourage the development of desirable communities. Restoration of reservoir ecosystems infested with exotic weedy species is beyond the scope of this report, but is considered elsewhere (Smart and Doyle 1995).

Finally, reservoirs with diverse and desirable aquatic plant communities may not require establishment of additional plant species. These systems should, however, be monitored and, if necessary, appropriate actions taken to ensure the continued health of the aquatic plant community.

### 3 Species Selection

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In an ecological sense, construction of a reservoir can be considered a major disturbance. Ecological theory predicts that, following a disturbance that destroys the plant community at a given site, the plant community will recover in a predictable successional sequence. The first colonizers are pioneer (r-selected) species that grow quickly and produce copious numbers of widely dispersed propagules (Stearns 1977). The prolific rates of reproduction and dispersal of these species allow them to spread quickly to fill adjacent available niches. Pioneer species are eventually displaced by longer lived, slower growing competitive plants (Grime 1979; Sheldon 1986). However, while pioneer species decline in abundance as competitive species proliferate, their seed remain in the seedbank. This seedbank provides a means for quick recovery of the vegetation if a subsequent disturbance sets the community back to an earlier successional state (van der Valk 1981; Sheldon 1986).

Unvegetated reservoirs will first require establishment of pioneer species. These plants modify the reservoir environment as they grow and expand, causing localized changes within the system that promote further expansion. Several mechanisms may work in concert to make reservoirs more hospitable as the plant community expands. These include increased sedimentation resulting in more shallow areas suitable for macrophyte growth (Carpenter 1981), increased water transparency because of reduced turbidity (Carpenter and Lodge 1986), reduced algal populations resulting from decreased water column nutrients (Kufel and Ozimek 1994), or shifts in the fish-zooplankton-phytoplankton interactions (Schriver et al. 1995). Pioneer species thus promote stability and provide conditions favorable for growth of higher successional aquatic plant species (Bertness and Callaway 1994; Grime 1979). In addition to altering the environment, the expanding plant community will develop greater tolerances to adverse environmental conditions as plant size and energy reserves accumulate (Olesen and Sand-Jensen 1994). This sets up a positive feedback process of community development that may lead to a stable, vegetated state.

## Life History Considerations

Native aquatic plants show great variability in terms of ecological benefits and ease of establishment. A list of native species that have been utilized for research-scale plantings is provided in Table 1. The plant types are categorized according to basic life histories exhibited in most southern reservoirs (winter annual, summer annual, perennating perennial, or evergreen perennial) and most common means of propagation (seed, stem fragments, tubers, turions, or vegetative expansion).

Plants that complete their entire life cycle in 1 year and survive from year to year strictly by seed can be broadly classified as summer or winter annuals depending on the season of maximum biomass. The seeds produced are typically resistant to environmental stress, but contain relatively little energy reserve (Madsen 1991). Because of the small energy reserves, developing seedlings are susceptible to unfavorable conditions or disturbances (varying water levels, high turbidity, water currents, herbivory, etc.) during the initial establishment period when seedlings are fragile and the population is sparse (Titus and Hoover 1991). Because annual plants survive from year to year by seed or spores (reproductive structures of macroalgae), these can be established in areas of the reservoir exposed during the plant's dormant period. In fact, the drawdown zone of Guntersville Reservoir, Alabama, which has a 50-cm winter draw, contains a diverse assemblage of native annual plant species, in sharp contrast to deeper waters that are dominated by Eurasian watermilfoil (Webb 1993). Because they are adapted to spread quickly, enhancement efforts in reservoirs with little existing vegetation should include several annual species.

Perennial plants are those that produce some form of vegetative tissue that survives for more than 1 year. Some perennials survive the winter in a dormant state by forming specialized perennating organs such as root crowns, tubers, or modified stem buds (turions). These dormant structures usually contain more energy reserves than seed (Madsen 1991) and can usually survive drawdowns or other unfavorable conditions. Subterranean tubers, in particular, allow vigorous growth once dormancy is broken (Kunii 1982; Titus and Adams 1979). Other perennials are evergreen, maintaining photosynthetically active leaves throughout the year. Depth of establishment is particularly important for these plants since they lack dormant perennating organs and are generally not well suited for quick recovery from exposure.

## Plants to Avoid

The harmful effects of certain exotic species like hydrilla on water resources such as water supply, hydropower production, navigation, and many forms of water-based recreation are well known (Langeland 1990). Like native pioneer species, hydrilla has characteristics that allow it to rapidly colonize open sites, and it has been advocated for use in unvegetated

<b>Table 1</b> <b>Species of Submersed Aquatic Plants That the Authors Have Utilized in Enhancement Efforts (An evaluation of the establishment methods attempted by authors is given as follows: (-) not recommended, (?) under investigation, (+) recommended, (++) strongly recommended, (±) variable results)</b>		
Plant Species	Plant Type and Common Means of Propagation in Nature	Methods of Establishment Attempted by Authors
Muskgrass <i>Chara vulgaris</i>	Summer annual Propagates by spores or vegetative fragments.	(+) peat-potted transplants (-) dry mudballs or burlap strips (?) sediment laden with spores
Southern naiad <i>Najas guadalupenses</i>	Summer annual Propagates by vegetative expansion, seed, or stem fragments.	(+) peat-potted transplants (?) sediment laden with seeds
Small pondweed <i>Potamogeton pusillus</i>	Winter annual Propagates by vegetative expansion, turions, seed, or stem fragments.	(+) peat-potted transplants (?) sediment laden with seeds
Horned pondweed <i>Zannichellia palustris</i>	Winter annual Propagates by seed, vegetative expansion, or stem fragments.	(+) peat-potted transplants (?) sediment laden with seeds
American pondweed <i>Potamogeton nodosus</i>	Tuber-forming perennial Propagates by vegetative expansion (rhizome), seed, stem fragments, or tuber production.	(+) tubers (+) peat-potted transplants (?) sediment laden with seeds
Sago pondweed <i>Potamogeton pectinatus</i>	Tuber-forming perennial Propagates by vegetative expansion (rhizome), seed, stem fragments, or tuber production.	(±) tubers (+) weighted bags with tubers
Vallisneria (northern) <i>Vallisneria americana</i>	Tuber-forming perennial Propagates by vegetative expansion (stolon), dormant tuber, or seed.	(+) tubers (+) peat-potted transplants
American elodea <i>Elodea canadensis</i>	Evergreen perennial Propagates by vegetative expansion or stem fragments.	(+) peat-potted transplants (+) stem fragments
Water star grass <i>Heteranthera dubia</i>	Evergreen perennial (in the South) Propagates by vegetative expansion, stem fragments, or seed.	(+) peat-potted transplants (+) stem fragments
Vallisneria (southern) <i>Vallisneria americana</i>	Evergreen perennial Propagates by vegetative expansion (stolon) or seed.	(+) peat-potted transplants (-) bare-root transplants (?) seed



reservoirs. However, unlike native pioneer species, hydrilla does not appear to be easily displaced by more desirable natives in a natural successional sequence (see Smart and Doyle 1995).

Unfortunately, many of the growth characteristics of hydrilla make it a very poor choice because it not only interferes with the use of water resources but also ultimately causes a deterioration in the quality of aquatic ecosystems. Hydrilla has a rapid growth rate and, since it readily grows from small stem fragments, also has a high reproductive capacity and tremendous dispersal capabilities. Hydrilla also tolerates low-light levels, has a well-developed ability to elongate, and produces a very dense, highly branched canopy at the water surface (Pieterse 1981). The surface mat can cause greatly reduced rates of mixing, water exchange, light penetration, and gas exchange—ultimately leading to depletion of dissolved oxygen in the water column (Honnell, Madsen, and Smart 1993).

These authors urge that because of the high potential for creating serious management problems, exotic species such as hydrilla and Eurasian watermilfoil be avoided entirely, even in completely unvegetated reservoirs. Although these plants may provide short-term benefits in unvegetated reservoirs, these are greatly outweighed by serious, long-term consequences. There are many submersed aquatic plant species native to this country that provide quality fish and wildlife habitat and do not usually cause significant problems with water resource use.

## Native Plants to Consider

### Annuals

Muskgrass (*Chara* spp.) and southern naiad (*Najas guadalupensis*), both summer annuals, are excellent pioneer species. Muskgrass is a macrophytic algae and lacks vascular tissues, including roots. This species is useful because it is easily established and provides broad benefits, including reduction of water column nutrients (Kufel and Ozimek 1994), increased water clarity, improved fish habitat, and reduced growth of nuisance species (Denike and Geiger 1976). However, it does not grow well in soft-water environments (Prescott 1978). As pioneer species, muskgrass and southern naiad expand and quickly cover the sediments with a carpet of vegetation. Both plants are replaced by higher successional, longer lived plants during natural community development.

Two desirable species of winter annuals are horned pondweed (*Zannichellia palustris*) and small pondweed (*Potamogeton pusillus*). These plants grow during a period of the year when many other species are dormant and facilitate the establishment of other species, including both summer annuals and perennials.

## **Tuber-forming perennials**

American pondweed (*Potamogeton nodosus*), sago pondweed (*Potamogeton pectinatus*), and the northern ecotype of vallisneria (*Vallisneria americana*) produce tubers. These tubers provide a vigorous propagule that can be stored for months. Although populations of all three tuber-forming species have been successfully established, American pondweed has been found to be particularly hardy and easy to establish even in very turbid reservoirs. Tubers collected from the field or from culture during the winter can be kept in dark containers within a refrigerator for several months with no apparent decline in viability.

The northern ecotype of vallisneria is perhaps the most commonly used species in enhancement efforts, and there is more information available on this species than any other (e.g., Korschgen and Green 1988). Unfortunately, vallisneria ranks very high on the food-preference order of several herbivores including red-eared turtles (Dick et al. 1995) and is often subject to high herbivory. Consequently, when planting this species in unvegetated reservoirs, herbivore protection is essential (see below). However, with these caveats, plantings of vallisneria tubers by the authors and others (e.g., Carter and Rybicki 1985) have often been successful. Vallisneria tubers are commonly available from northern suppliers.

American pondweed has proven particularly easy to establish from tubers (e.g., Doyle and Smart 1993) and, because it forms floating leaves, can be used even in very turbid reservoirs.

## **Evergreen perennials**

Three species that are evergreen perennials in southern waters have been used for establishment efforts: vallisneria (southern ecotype), water-star grass (*Heteranthera dubia*), and elodea (*Elodea canadensis*).

The southern ecotype of vallisneria is an evergreen perennial that does not produce tubers (Smart and Dorman 1993). Therefore, this ecotype must be propagated by either transplants or seed. This ecotype is typically larger and spreads more rapidly than the northern ecotype when planted in southern waters.

Water star grass is often observed in reservoirs in the South. Because it grows in relatively small, dense clumps, it may prove to be an excellent plant for providing structure and edge environments for fish habitat. Field establishments have mostly utilized mature transplants, although the species has been established utilizing stem fragments rooted in small peat pots and even fresh stem cuttings (Doyle and Smart, In Preparation).

Elodea is a common, turbidity-tolerant component of northern plant communities (Nichols 1992) and may prove to be a valuable pioneer species in

southern waters. The lush growth of the species forms a stabilizing carpet over the sediment, which, in combination with the filtering effect of its leafy shoots, improves water clarity. Elodea, adapted for the lower temperatures of the northern United States, remains active during much of the winter in the South. This evergreen perennial thus provides the benefits of submersed vegetation during a period of the year when many other plant species are inactive. Although the growth of elodea may be depressed under the high midsummer temperatures of the South, this may be an advantage since it will be less likely to interfere with utilization of the water surface at that time of year. Also, more heat-tolerant species are afforded an opportunity to develop.

Although elodea superficially resembles hydrilla, it generally does not cause as many problems with water resources in reservoirs. Elodea exhibits a lower growth profile than hydrilla, usually forming a canopy well below the water surface. This native plant should also not be confused with Brazilian elodea (*Egeria densa*), another exotic species that can cause management problems.

## 4 Project Implementation

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### Propagule Acquisition

Propagule acquisition will comprise a large part of the effort for any establishment project. Careful consideration at this point will be well worthwhile since various options exist.

#### Commercial nurseries

Propagules of some species of submersed aquatic plants are available from commercial nurseries or suppliers. One major consideration when purchasing plants is the genetic source or origin of the plants. In general, establishment efforts should use plants obtained from a latitude or climate similar to that of the project site. Particular care must be taken with regard to the popular *vallisneria*, which has ecologically distinct northern and southern ecotypes. Another consideration is contamination of plants with unwanted species. Shipments from commercial vendors with fragments of hydrilla among the plants have been received occasionally.

An alternative to commercial suppliers is to contract with local aquatic nurseries to obtain and propagate local ecotypes for specific projects. This approach offers the convenience of purchasing the propagules, while maintaining control over the genetic stock of the plants.

#### Collection from the wild

Rooted, growing plants or dormant tubers collected from donor sites have often been used in restoration efforts. However, given the high impacts on the donor site and the high mortality often associated with transplants, the belief is that this is a poor option unless trained personnel are available, transplants can be planted immediately after collection, and pilot-scale plantings have proven successful. Otherwise, the restoration effort may fail, and the donor site may likewise be damaged.

In cases where abundant local donor sites and trained personnel are available, logistic obstacles are minimal, and pilot tests have demonstrated a high potential for success, collection from the field can produce good results. The Florida Game and Fresh Water Fish Commission reports that transplants of *vallisneria*, carefully collected from local donor sites and immediately planted within fenced exclosures in Lake Monroe, suffered little mortality and provided excellent growth. In 1992, 18,000 transplants were established within a 2-ha exclosure. One year later, about half of the planted plots contained "topped out" vegetation, and the total number of plants within the exclosure was estimated at 4.7 million.<sup>1</sup>

Collection of seed from donor sites offers a more responsible alternative since potential damage to the donor site is minimized. Successful collection of seed requires careful monitoring of the donor population to ensure that seed are harvested after ripening but prior to release by the plant. Viable seed are also likely present in the sediments within and adjacent to established populations, and seed-laden sediment might be easily collected during low-water periods.

### **Propagation**

For large-scale, long-term efforts where greenhouse or pond facilities are available, it may be worthwhile to mass culture plants for propagation stock. Plants may be propagated to produce seed, tubers, stem fragments, or to be used as live transplants.

Shallow ponds are ideal for the production of seed of many species. The research ponds at the Lewisville Aquatic Ecosystem Research Facility (LAERF), Texas, with populations of several submersed plants, have been manipulated to enhance production of spores or seeds of muskgrass, southern naiad, and American pondweed (Dick and Smart 1992). The clay-lined ponds, originally part of the fish hatchery operations of the Texas Parks and Wildlife Department (TPWD), range in size from 0.2 to 0.8 ha and up to 2 m in depth.

A system of periodic drawdowns is used to promote germination, growth, and seed production of these species, and distinct patterns have been observed in the development of the plant communities in the ponds following flooding. Two to three weeks after flooding, the ponds are dominated by muskgrass; but after about 10 weeks, other species, primarily southern naiad, begin to achieve dominance. After adequate time for seed and spore production has passed, the ponds are drained and allowed to dry. The top sediment (5 cm) can then be scraped to collect spores and seeds. This mixture of sediments and dormant seeds/spores can easily be stored and later surface broadcasted over appropriately protected sites. Counts of germinating muskgrass spores and

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<sup>1</sup> Personal Communication, 1994, L. Ager, Florida Game and Fresh Water Fish Commission.

southern naiad seeds from sediments prepared in this way have exceeded 16,000 and 400 per square meter, respectively. Allowing the sediment to dry increases germination rates of both spores and seeds (Dick and Smart 1992).

Near monospecific cultures of muskgrass can be obtained by increasing the drawdown frequency. Since muskgrass reaches maturity and produces spores more quickly following flooding than other annuals, the flood/drain regime of the pond can be optimized to allow time for muskgrass spore production but not for seed production by other species. At the facilities in Texas, the ponds are flooded for about 10 weeks during the summer before draining.

Aquatic herbicides have also been used in conjunction with less frequent drawdowns to develop muskgrass monocultures. The advantage of this approach is that the longer period of growth allows for development of more vigorous plants and correspondingly greater density of spores. Many contact herbicides do not affect muskgrass (an alga) when used at label rates, but easily control most other annual species.

Production of southern naiad seed, or a mix of those and muskgrass spores, has been achieved by maintaining flooded conditions for a greater period of time. In LAERF ponds, southern naiad grown from seeds requires about 12 weeks of growth before producing seed. Seed production slows after about 16 weeks. If muskgrass is not desired in the culture, it might be eliminated by using noncopper algicides early in the flood cycle before it becomes well established.

Production of American pondweed seed can also be accomplished easily in ponds. Plants growing from tubers reach maturity relatively quickly, and seeds begin to set after about 10 weeks of growth. After about 16 weeks, seeds reach maturity and begin to drop from the plants.

When ponds are kept flooded during the fall and winter months, other species, including horned pondweed and small pondweed, often comprise a significant portion of the plant community. Sediment collected from these ponds and distributed in others has resulted in successful establishment of these winter annuals.

Seed can also be harvested from numerous other species such as vallisneria. Fruit pods are produced in summer and can be collected in the fall when the seeds turn black. Air drying ripe seed pods for about 2 weeks increases the germination percentage from 10 to 15 percent to 80 to 90 percent. To date, field-collected seed of vallisneria only have been used to start transplants for growth in culture. Although an attempt has not been made to establish this species directly from seed, establishment of seedlings have been observed in several research ponds and in Toledo Bend Reservoir, Texas.

Tuber-forming species may be grown to produce tubers in containers within in a greenhouse or pond. After the plants senesce, the containers can

be removed from water and stored for several months until the tubers are needed.

While the transplanting of actively growing plants from culture offers the best odds of short-term success, the greenhouse culture of most species of submersed aquatic plants requires rather exacting conditions (Smart and Barko 1985) and should not be attempted in the absence of proper facilities. The primary requirements are the provision of fertile sediment (pond sediment, if possible), low phosphorus water ( $< 10 \mu\text{g/liter}$ ) to prevent excessive growth of algae, moderate temperature (20 to 28 °C), and adequate light (35 to 65 percent of full sunlight). However, given suitable culture conditions, peat-potted transplants can be grown in outdoor tanks, raceways, or small ponds.

## **Establishment in the Field**

Aquatic plants exist in a dynamic, fluctuating environment at the interfaces between land, water, and air. In reservoirs, submersed aquatic plants typically grow in a band defined primarily by seasonal water level fluctuations and water clarity. The upper limit is determined by exposure during water level fluctuations (Keddy 1983) and may differ for annual and perennial species (Rorslett 1985). The lower limit will be set by the availability of sufficient light for photosynthetic growth (Spence 1982; Chambers and Prepas 1988). These basic physical limits are secondarily modified by other factors including temperature (Barko, Hardin, and Matthews 1982), sediment composition (Spence 1982), littoral slope (Duarte and Kalff 1986), and water flow velocities (Brewer and Parker 1990; Spence 1982).

These authors believe that, given the usual financial constraints and harsh environmental conditions in most poorly vegetated reservoirs, restoration efforts should focus on establishing small "founder" populations of native plants. This approach involves establishing small protected plots of plants at carefully selected sites known to provide appropriate hydrologic, edaphic, and environmental conditions for the species and type of propagule being used. The established populations will then provide propagules to vegetate the remainder of the available habitat in the reservoir. This method also offers the advantage of being easy to monitor and quantify. While macrophyte communities are adapted to environmental changes such as water level fluctuations (Brock 1988), the experience of these authors has been that the difficulty of initial establishment will increase with the amplitude of water level fluctuations during the growing season and with decreasing water clarity.

### **Protection of plantings**

The establishment of small founder populations involves providing some protection for the plants during the establishment phase. Because of the small size of these populations, they are inherently susceptible to destruction by water currents and herbivores. The establishment efforts that these authors

have been involved in have benefited dramatically from construction of exclosures or protective wave barriers. In most cases, plantings without protection were completely lost within the first few weeks (Doyle and Smart, In Preparation; Madsen et al. 1993). Other establishment efforts report similar experiences (Kollar 1985, 1988; Engel and Nichols 1991)

One inexpensive method for providing herbivore protection is the construction of small exclosures from commercially available plastic fencing and steel rebar (Figure 2). The orange plastic fencing is superior to wire netting because it is highly visible to boat traffic and, because it does not rust, will last two seasons in the water. The exclosure can be assembled on land and easily deployed in up to 1.25 m of water.

There may be a need to provide wind or wave protection in addition to herbivore exclusion. Field surveys of Onondaga Lake suggested that wave action severely limited plant growth in the lake (Madsen et al. 1993), and, although this problem was exacerbated in Onondaga Lake by the flocculent character of the sediments, many establishment efforts would benefit from wave protection.

In Onondaga Lake, a 100-m wavebreak was constructed at each of two sites (Figure 3). The wavebreaks were made of hay bales held in place by wooden stakes driven through the bales and supplemented with periodic T-posts outside the bales. Baling wire was then wrapped between T-posts to bind the wavebreak together, and the entire structure was covered with a coconut fabric to add additional resiliency. Herbivore exclosures were erected behind the wavebreaks.

The combination of protection from herbivores and protection from wave action allowed abundant and diverse growth of aquatic plants in the plots (Madsen et al. 1993). Although the plots behind the wavebreaks were planted with only three species, as many as seven other unplanted species became established. At one site, the reference plot had five different species, while the planted plot had ten. Three species in the fenced planted plots had not been seen growing in the lake during the reconnaissance phase of study. At the second site, only one species grew in the unmanipulated reference, while nine species were recorded from the protected fenced plot. Of these, only three had been planted and two had not previously been observed in the lake.

Although the wavebreaks lasted only one season, they were relatively inexpensive to construct and greatly contributed to the success of the restoration project. In this case, protection from waves and herbivores not only allowed survival and growth of the transplanted species, but also promoted the growth of a diversity of species already present in the lake as dormant seed. The appearance of several "volunteer species" in the protected sites demonstrates the resilience of seedbanks in natural lakes that have lost the submersed flora because of anthropogenic impacts. Artificial reservoirs that have never had a diverse submersed plant community will not respond in similar fashion because the seedbank will not be present in the sediments.



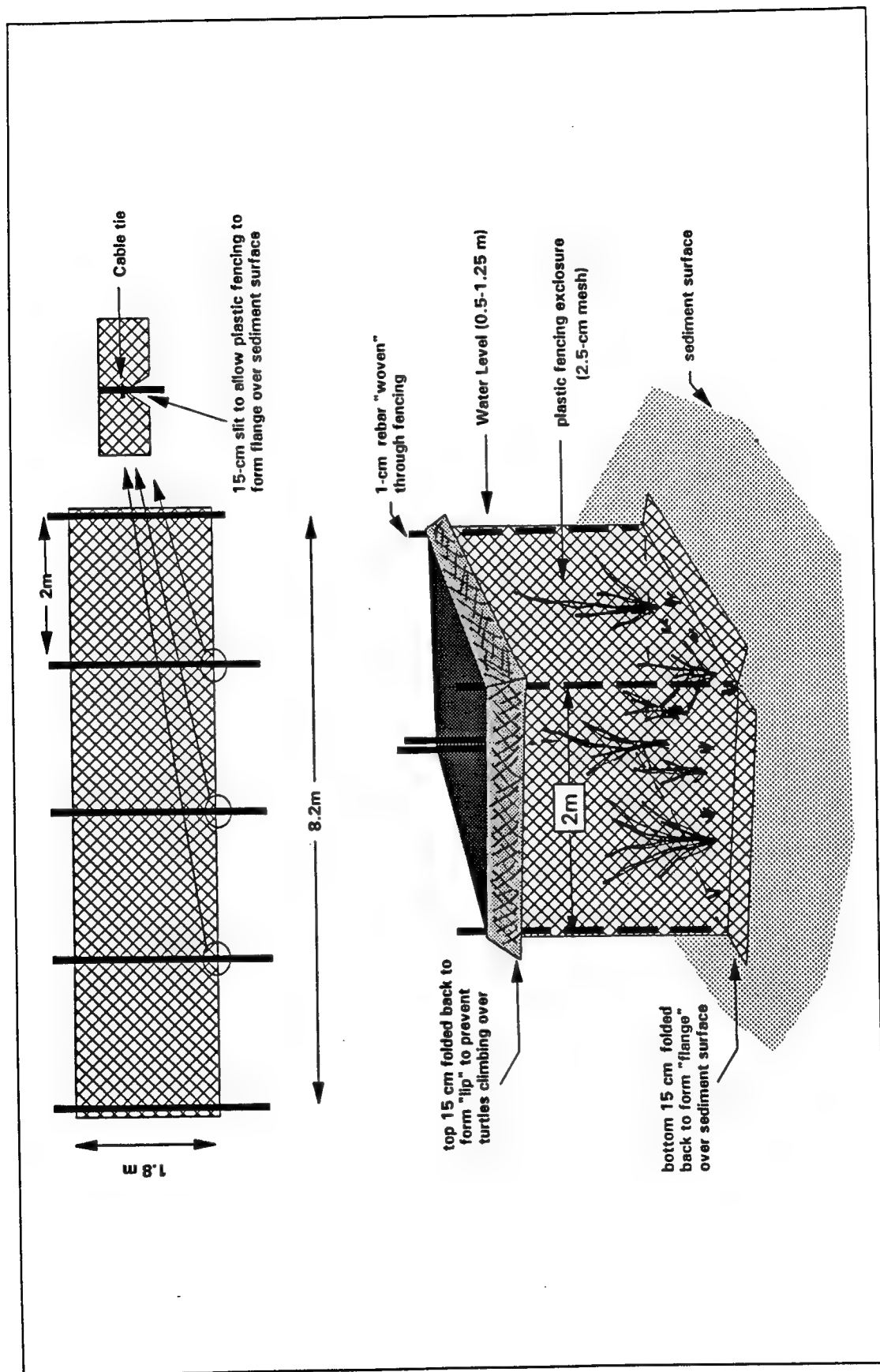


Figure 2. Design for small enclosure

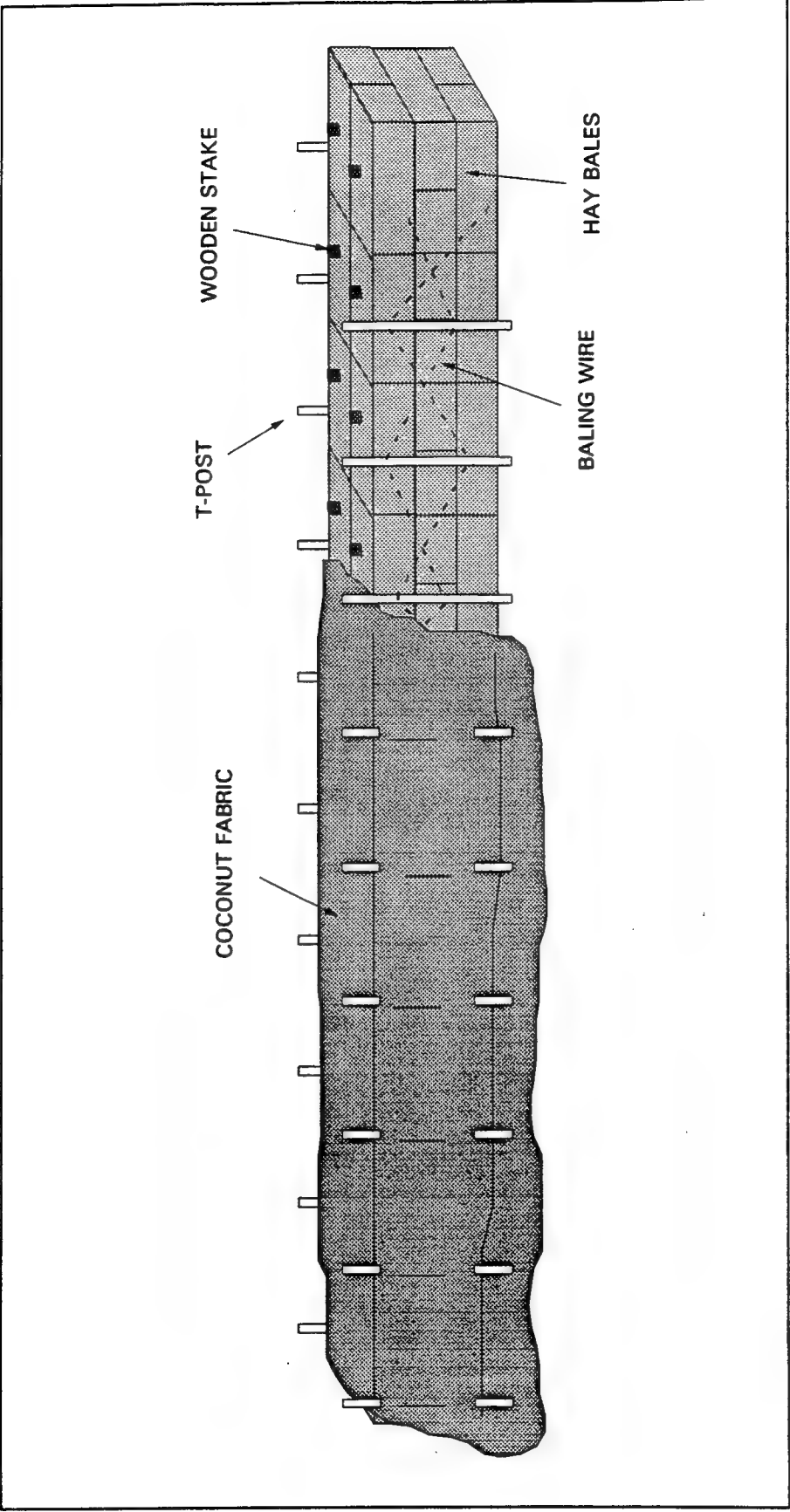


Figure 3. Design for hay bale wavebreak

## Planting options

Ideally, the most cost-effective method for establishing native plants is to broadcast seed on appropriate sites. However, the small energy reserves contained in seeds requires that the developing seedling quickly achieve photosynthetic self-sufficiency (Madsen 1991). Therefore, seeds should be planted in shallow but protected areas. As a general rule, these authors suggest that they be planted at a depth less than or equal to the average Secchi depth during the growing season.

Many plants produce viable stem fragments that can serve as an effective means of propagation. These plants offer the advantage that a single plant growing in culture (or in the field) can be "harvested" to provide many propagules. However, such stem cuttings are delicate, subject to desiccation, and must be handled with care in order to retain viability. Also, because stem fragments must sustain high photosynthetic rates during the first weeks as they establish roots, they should be planted in relatively high light ( $< 1$  Secchi depth) and low turbulence environments.

Plants that produce dormant tubers provide one of the most economical and effective means of establishment. The anchorage and energy reserves provided by the tubers enable these plants to withstand moderate currents and survive lower light levels. Tubers tolerate handling during transplanting to the field and can be planted at water depths up to 2 Secchi depths. To keep the tubers from being washed away, they can be hand-planted to a depth of 5 cm beneath the sediment surface or scattered in weighted cotton mesh bags. Because tuber-forming perennials are dormant during the winter, they can survive in the drawdown zone of reservoirs with a winter draw.

If culture facilities are available, most species can be reliably established in the field utilizing live transplants. Transplants contain larger energy reserves and tolerate water depths up to twice the Secchi depth. Commercially available peat pots offer an excellent way to culture submersed plants and allow propagules to be transported to the field with minimal disturbance. The advantages of utilizing transplants for establishing natives is that the highlight/low-turbulence environment needed for initial germination and growth of seedlings or shoot fragments can be provided under controlled conditions. Therefore, the selection of field planting sites is more flexible. However, facilities necessary for culture may not be available, and the additional costs of materials and labor may be prohibitive.

Transplanting actively growing plants to the field offers the most reliable method of guaranteeing short-term survival. However, research has indicated that transplants that are uprooted before transplanting (bare-root transplants) suffer much higher mortality than peat-potted plants that are transplanted with an undisturbed root system (Doyle and Smart 1993). The observation was also made that the tissues of many plants are buoyant, and bare-root transplants were very easily uprooted and floated away.

## Monitoring

Monitoring the results of establishment projects is critical for long-term evaluation of the benefits provided by these efforts. A common problem in wetland creation has been inadequate monitoring (Kentula et al. 1993), and monitoring of submersed plantings, with their limited visibility and higher susceptibility to damage, is even more critical. Without information on the possible causes of failed efforts, much progress in this area will not be made. Fortunately, several simple monitoring methods are available for the types of plantings discussed.

If small numbers of transplants are utilized and planted in a pattern, short-term monitoring can simply involve counting the number of clumps within an enclosure. As the clumps begin to grow together, visual estimates of the percent cover of the plants within the plot or enclosure are made. Since most plantings discussed in this article involve shallow depths, an observer should be able to see to the plants within the enclosures and quickly make the measurements.

A method that is useful for larger scale and longer term evaluations is the use of line transects (Titus 1993). This method can be used for either permanent or random transects and offers the advantage of providing an easily interpreted estimate to monitor the long-term development of a community. Specific instructions and data sheets for line transect surveys are presented in Appendix A.

Monitoring should be continued even after the initial establishment phase in order to "fine-tune" the species composition of the community. Desirable species that are lacking or present in low quantities can then be selectively added to the plant community.

## 5 Reviews of Recent Establishment Efforts

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Research-scale plantings have been conducted by the authors at four sites: Lake Onondaga, New York, Lake Guntersville, Alabama, a created wetland in Texas (Ray Roberts wetland complex), and in two north Texas reservoirs.

Lake Onondaga, a natural lake near Syracuse, NY, has a long history of domestic and industrial effluent discharges that have resulted in high salinity (up to 3 ppt), low transparency ( $< 1$ -m Secchi depth), and a highly calcareous sediment low in nutrients (Effler 1987; Madsen et al. 1993). Because of these environmental constraints, the aquatic plant community in Onondaga Lake was virtually nonexistent in 1991.

Lake Guntersville is the second largest of the main stem Tennessee River reservoirs operated by the Tennessee Valley Authority (TVA) and is located in northeastern Alabama and southeastern Tennessee. The dam impounds a 75.7-mile-long<sup>1</sup> reservoir that provides a maximum volume of 1,018,000 acre-feet (TVA 1992). This multipurpose reservoir was designed for and is routinely operated to provide navigation, flood control, and power production. Secondary benefits of the project include recreation, water supply, and fish and wildlife habitat. Guntersville Reservoir has the most significant aquatic plant infestation of the reservoirs within the Tennessee River system, and in 1989, Congress authorized a 5-year aquatic plant management program for Guntersville Reservoir. This program, jointly implemented by the U.S. Army Corps of Engineers (USACE) and TVA, focused on developing or testing innovative aquatic plant management methodologies (Bates, Decell, and Swor 1991). Plantings were conducted within Guntersville Reservoir as part of the Plant Competition work unit of the Guntersville Joint Agency Project (Doyle and Smart 1993; Doyle and Smart, In Preparation).

The wetland complex at Lake Ray Roberts, Texas, consists of six cells totaling 176 acres of wetlands (Doyle, Dickson, and Sturges 1993). It is located on the floodplain of Range Creek and receives water passively from

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<sup>1</sup> A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

creek flooding or rainfall events. Although water-level control structures allow the wetlands to be drained, there are no provisions for pumping water into the cells during dry periods. Experimental plantings of native aquatic and wetland plants were conducted between 1992-1994 under funding from the U.S. Environmental Protection Agency and the Fort Worth District Corps of Engineers (Doyle and Smart, unpublished data).

Finally, establishment of submersed and floating-leaved aquatic species has been undertaken to provide fish habitat in two north Texas reservoirs in conjunction with TPWD (Doyle, Smart, and Guest, unpublished data). Lewisville Lake is a large main stem reservoir with turbid water. It has few aquatic plant species and an annual water level fluctuation of about 8 to 10 ft. North Lake is a small cooling-water reservoir with muted water level fluctuations (<2 ft), clear water, and a history of extensive hydrilla infestation. Following a successful herbicide treatment for hydrilla in 1992, the lake showed a strong regrowth of several native pioneer species.

## Annuals

Both peat-potted transplants and seed/spore dispersal have been used in efforts to establish these pioneer species in unvegetated areas. The greatest success using transplants was at the Ray Roberts wetland. Small peat pots of pond sediment from research ponds at the LAERF were kept in shallow raceways for several months during the winter, allowing the seeds and spores within the sediment to germinate and grow prior to being transplanted to the wetland in the spring of 1993. Continued monitoring of the wetlands in 1994 has shown that the established populations have continued to grow and expand.

A much less effective attempt to establish populations of these species in the created wetland involved utilizing dried mudballs impregnated with muskgrass spores and southern naiad seeds. The top layer of sediment, which contained a high number of spores and seed, was collected from culture ponds at the LAERF, shaped into small (ca. 1-cm-diam) balls, and allowed to air dry. These mudballs were distributed within marked but unfenced plots within the wetlands at water depths ranging from 30 to 50 cm at a density of 25 per square meter. Although both species readily grew from mudballs incubated in shallow water trays in a greenhouse, evidence of growth was never seen in the field.

Another largely unsuccessful approach was to transport burlap blankets impregnated with spores and seeds to Lewisville Lake. The burlap fibers were intended to provide a protected microenvironment for germination and early growth. Burlap strips approximately 1 m wide and 15 m long were positioned in a dry, tilled pond that had previously been used for the culture of muskgrass and southern naiad for several seasons. The burlap was lightly coated with dry surface sediments from the ponds, and then the pond was

reflooded. As expected, there was a rapid growth of the two annual plants from the sediment overlying the burlap. After about 3 months of growth to allow the plants to form seed or spores, the pond was drained. After a 2-week period to allow the surface sediments to dry out, the burlap strips and overlying sediment and dried-out plants were rolled up and transported to exclosures constructed in the reservoir. Transplanting to the field took place in September 1993 in water depths ranging from 25 to 30 cm. Unfortunately, the water level of the reservoir was raised shortly thereafter and was much higher (1.5 m) during most of the winter/spring of 1993-1994, as flood waters from the seasonal fall rains were retained in the reservoir. In the spring/summer of 1994, when the water levels returned to normal, no growth of either of the target annuals was seen. It is possible that the light levels in this very turbid portion of the reservoir were inadequate to sustain early growth, that the high water levels simply washed away most of the spore and seed, or perhaps a thick layer of sediment deposited on the blankets buried the spore and seed too deeply. Although potential reasons for the failure of this operation were many, the enormous effort of preparing and transporting the burlap blankets to the field renders this method an ineffective way of establishing these annual plants. However, if one wanted to try this method again, culturing the burlap blankets so that they could be taken to the field in early summer is recommended. This would likely allow the seeds to germinate, grow, and set seed before the onset of winter.

A simpler approach recently investigated involves the use of dried surface sediments (containing dormant seed and spores) from culture ponds. Approximately 100 l of sediments were broadcast within each of several 36-m<sup>2</sup> exclosures in shallow areas (<2 ft) of Lewisville Lake and Ray Roberts wetlands. The exclosures were made of 1-m-wide silt fencing and anchor stakes. This method offers the advantages of relatively low labor and a high potential for being scaled up for larger plantings. Initial establishment of both summer and winter annuals has been observed at the created wetland site.

A propagation method not used but which is recommended by commercial suppliers of aquatic plant propagules is to simply rake up living plants from the bottom of ponds and transport them immediately to small exclosures within the lake.

## **Tuber-Forming Perennials**

Small populations of American pondweed have been established from tubers at various sites in Guntersville Reservoir (Doyle and Smart 1993). These have typically been successful during the first year, although the need for herbivore protection (from grass carp, turtles, and muskrat) is critical in this reservoir. In Guntersville Reservoir, successful establishment within protected plots were commonly observed, but there was often no spread of the plant outside of the fenced exclosures. Test plots planted adjacent to the exclosures, but with no protective fencing, routinely failed to show any signs of growth because the developing plants were grazed immediately. In some

cases, even with the protective fencing, significant herbivory problems were experienced. Turtles were observed to climb over the fencing and into the plots. In at least one instance, an entire 50-m<sup>2</sup> plot was decimated by muskrat (Doyle and Smart, In Preparation).

American pondweed tubers were also utilized in the vegetation establishment effort at the created wetland in Texas. Tubers were planted in 4-m<sup>2</sup> enclosures constructed of plastic fencing built within small (20-m-diam, 1.5-m maximum depth) ponds. Although success was variable, the plants spread throughout several of the ponds in just a few months. American pondweed can also be propagated by stem cuttings. Under ideal conditions, stem cuttings may be planted directly in the field; but these authors recommend planting 15-cm cuttings in peat pots and allowing 4- to 8-weeks growth prior to transplanting to the field. These types of transplants have been used recently in Lewisville Lake; after 1 year of growth in the field, three of the six plots showed establishment and expansion. Short-term success would likely be higher if the initial plantings could have been made with dormant tubers or more established transplants.

Finally, seed also offer an attractive possibility for establishing American pondweed, although this option has not been carefully investigated in reservoir situations. Within the culture ponds, American pondweed sets flowers and produces seed prolifically. These are easily collected and can likely be stored dry for months. Seedbank studies indicate that the sediments of the culture ponds contain high numbers of viable seed. In fact, when the attempt was made to establish muskgrass and southern naiad with the burlap strips (discussed above), the only plant that grew was American pondweed. Presumably, the plants grew from seed contained within the sediments overlying the burlap strips.

Plantings of sago pondweed tubers were conducted in both Guntersville Reservoir and at the created wetland site in Texas with poor results. In both cases, the tubers were purchased from a commercial vendor in Wisconsin and refrigerated for up to 3 months prior to planting. While greenhouse experiments and pond plantings demonstrated the viability of the tubers, successful establishment of this species in Texas and Alabama has not yet been obtained.

Tubers of both pondweed species have also been used in a restoration effort in Onondaga Lake, New York. Because of the unusual and rather stressful conditions, sediment and water chemistry bioassays were performed to select species with the greatest potential for success. American and sago pondweed were identified as good candidates for this restoration effort (Madsen et al. 1995). In-lake plantings of American and sago pondweed were attempted in Onondaga Lake in 1992. Dormant tubers were planted under approximately 5 cm of sediment in exposed and protected sites under two treatments: bare sediment and under a geotextile mat; no herbivore protection was provided for either treatment. Sago pondweed survival after 4 weeks was significantly different between the two sites, with less than 10-percent survival for both treatments at the exposed site. In contrast, at the protected site,



survival was 97 percent in the bare sediment treatment and 55 percent under the geotextile mat. American pondweed performed poorly, with less than 10-percent survival after 4 weeks for both treatments at both sites.

During 1993, sago pondweed was planted in 15- by 5-m blocks within protective exclosures at two locations. Approximately 500 tubers were planted as weighted sacks buried in 5 cm of sediment within each block. Although tuber-specific survival data were not collected, sago pondweed germination rates appeared good; a final coverage of 15 percent of sago pondweed within the blocks at each of the two locations was achieved.

Tubers and peat-potted transplants of the northern ecotype of *vallisneria* were planted in Guntersville Reservoir as part of a plant competition study (Doyle and Smart 1993). The tubers were collected during the winter from the Holston River, Tennessee, and refrigerated for 2 or 3 months at 5 °C until being planted in the field. While the short-term success was good, two problems were encountered with establishment. First, the effort took place during a period when the reservoir's plant community was experiencing a general decline, and unconsolidated sediments and high turbidity were complicating factors. In addition, *vallisneria* ranks very high on the food-preference order of grass carp and red-eared turtles. While the exclosure effectively prevented grass carp from grazing the plots, turtles were less effectively excluded. Consequently, when planting this species in unvegetated reservoirs, herbivore protection is essential (see below). However, with these caveats, plantings of *vallisneria* tubers by the authors and others (e.g., Carter and Rybicki 1985) have often been successful.

## Other Perennials

Transplants of water star grass were used to vegetate portions of the created wetland in Texas during the summer of 1994. For this effort, 15-cm stem cuttings were planted in 6-l containers in a shallow pond for approximately 6 weeks before transplanting to the field. At that time, the cuttings had rooted and had grown to about 30 cm in length. Although only qualitative evaluations have been made, these transplants have survived their first year in the field and many have shown vigorous expansion.

Cuttings of water star grass were also planted within Guntersville Reservoir as part of a plant competition study (Doyle and Smart, In Preparation). Apical tips (15 cm) were planted in an unvegetated area at a planting density of 50 cuttings per square meter. The stem fragments were held in place by a polyvinyl chloride planting frame criss-crossed with nylon cord. Although the depth at which the stem fragments were placed was probably deeper than optimal for this type of planting ( $\approx 1.5$  Secchi depths), successful establishment was observed in several of the planted plots. Plants within those plots grew to the surface and flowered within about 3 months of planting.

To date, *Elodea* has been used only to establish culture ponds for research. Establishment has been obtained with both peat-potted transplants and fresh stem cuttings. However, the establishment conditions within the LAERF research ponds are near ideal (high light transparency and low turbulence), and stem cuttings may not do as well under reservoir conditions.

Small populations of the southern ecotype of *vallisneria* were established in Guntersville Reservoir from peat-potted transplants despite poor conditions imposed by high turbidity and heavy herbivory (Doyle and Smart 1993; Doyle and Smart, In Preparation). Small plots were planted within a larger enclosure, and some of the plots were initially destroyed by herbivory. Although *vallisneria* is not recommended for these adverse conditions, some of these small populations have persisted for over 3 years despite a massive reinfestation of Eurasian watermilfoil (Doyle and Smart 1995).

In Texas, nine 4-m<sup>2</sup> plots of *vallisneria* were planted in North Lake, which already supported a broad mix of natives. Five transplants grown in 6-l containers were planted in each fenced plot. After one growing season, all of the plots showed greater than 80-percent survival of the plants. In five of the plots, the *vallisneria* transplants had expanded to completely fill the plots and were expanding outside of the exclosures. One plot, growing under optimal conditions, increased 1,000-fold in area during a single growing season. Six 4-m<sup>2</sup> plots were also planted with mature transplants at the created wetlands in Texas in July 1994. After 1-year growth, plants within the exclosures have shown 100-percent survival and, in many cases, have expanded to completely fill the exclosures.

## 6 Conclusions

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Reservoirs are complex and constantly changing ecosystems, and the development of mixed native plant communities can provide new and important dimensions in habitat and ecosystem stability. In addition to benefiting fisheries, native plant communities will further enhance the environment by providing valuable habitat for waterfowl, water quality benefits (including increased clarity and nutrient uptake and immobilization), resilience to recover from disturbances, and resistance to invasion by nuisance exotics.

While research into the reasons for successes or failures of specific planting attempts continues, experience points to the necessity of diversifying efforts by utilizing a variety of species and locations. In multiple and seemingly identical efforts, some plantings are commonly observed to fail while others flourish. Establishment of aquatic plants under reservoir conditions is still far from an exact science and, as a result, remains difficult and expensive. In spite of these current limitations, the belief is that documented efforts to establish native plants will ultimately yield rich dividends. Such efforts will serve to establish quality shallow water habitats, which are often lacking in reservoir systems.

# References

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- Barko, J. W., Hardin, D. G., and Matthews, M. S. (1982). "Growth and morphology of submersed freshwater macrophytes in relation to light and temperature," *Can. J. Bot.* 60, 877-887.
- Bates, A. L., DeCell, J. L., and Swor, C. T. (1991). "Joint Agency Plan, Aquatic Plant Management on Guntersville Reservoir," Tennessee Valley Authority, Muscle Shoals, AL, and U.S. Army Corps of Engineers, Washington, DC.
- Bertness, M. D., and Callaway, R. (1994). "Positive interactions in communities," *Trends in Ecology and Evolution* 9, 191-193.
- Brewer, C. A., and Parker, M. (1990). "Adaptations of macrophytes to life in moving water: Upslope limits and mechanical properties of stems," *Hydrobiologia* 194, 133-142.
- Brock, M. A. (1988). "Flexibility of life cycle pattern as a mechanism for tolerance of fluctuations of environmental conditions by aquatic plants," *Ver. Internat. Verein. Limnol.* 23, 1949-1953.
- Butler, R. S., Moyer, E. J., Hulon, M. W., and Williams, V. P. (1992). "Littoral zone invertebrate communities as affected by a habitat restoration project on Lake Tohopekaliga, Florida," *J. of Freshwater Ecology* 7, 317-328.
- Carpenter, S. R. (1981). "Submersed vegetation: An internal factor in lake ecosystem succession," *The Am. Naturalist.* 118, 372-383.
- Carpenter, S. R., and Lodge, D. M. (1986). "Effects of submersed macrophytes on ecosystem processes," *Aquat. Bot.* 26, 341-370.
- Carter, V., and Rybicki, N. B. (1985). "The effects of grazers and light penetration on the survival of *Vallisneria americana* Michx in the tidal Potomac River, Maryland," *Aquatic Botany* 23, 197-213.

- Chambers, P. A., and Prepas, E. G. (1988). "Underwater spectral attenuation and its effect on the maximum depth of angiosperm colonization," *Can. J. of Fisheries and Aquatic Sciences* 45, 1010-1017.
- Denike, T. J., and Geiger, R. W. (1976). "The utilization of Chara in water management," *Hyacinth Control Journal* 12, 18-20.
- Dick, G. O., and Smart, R. M. (1992). "Management of endemic aquatic macrophytes in warmwater ponds." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program*. Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 26-29.
- Dick, G. O., Smart, R. M., and Keiser, E. D. (1995). "Turtles and their potential impact on aquatic plants in Guntersville Reservoir, Alabama," Guntersville Joint Agency Project, Tennessee Valley Authority Technical Report.
- Doyle, R. D., Dickson, K., and Sturges, D. (1993). "Created wetlands on Lake Ray Roberts, Texas: Design, pre-impoundment status, and research opportunities." *Wetlands: Proceedings of the 13th Annual Conference of the Society of Wetland Scientists, New Orleans, LA*. Mary Landin, ed., South Central Chapter, Society of Wetland Scientists, Utica, MS, 827-834.
- Doyle, R. D., and Smart, R. M. (1993). "Potential use of native aquatic plants for long-term control of problem aquatic plants in Guntersville Reservoir, Alabama; Report 1, Establishing native plants," Technical Report A-93-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- \_\_\_\_\_. "Potential use of native aquatic plants for long-term control of problem aquatic plants in Guntersville Reservoir, Alabama; Report 2, Competitive interactions," Technical Report in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Duarte, C. M., and Kalff, J. (1986). "Littoral slope as a predictor of the maximum biomass of submerged macrophyte communities," *Limnol. Oceanogr.* 31, 1072-1080.
- Effler, S. W. (1987). "The impact of a clor-alkali plant on Onondaga Lake and adjoining systems," *Water, Air and Soil Pollution* 33, 85-115.
- Engel, S. (1985). "Aquatic community interactions of submerged macrophytes," Wisconsin Department of Natural Resources Technical Bulletin 156.
- Engel, S., and Nichols, S. A. (1991). "Restoring Rice Lake at Milton, Wisconsin. Shallow Lakes Initiative Final Report," Wisconsin Department of Natural Resources. Madison, WI.

- French, J. R. P. (1988). "Effect of submersed aquatic macrophytes on resource partitioning in yearling rock bass (*Ambloplites rupestris*) and pumpkinseeds (*Lepomis gibbosus*) in Lake St. Clair," *J. Great Lakes Res.* 14(3), 291-300.
- Godshalk, G. L., and Barko, J. W. (1985). "Vegetation succession and decomposition in reservoirs." *Microbial processes in reservoirs*. D. Gunnison, ed., Dr. W. Junk Publishers, Dordrecht.
- Grime, J. P. (1979). *Plant strategies and vegetation processes*. John Wiley and Sons.
- Hammer, D. A. (1992). *Creating freshwater wetlands*. Lewis Publishers, Chelsea, MI.
- Honnell, D. R., Madsen, J. D., and Smart, R. M. (1993). "Effects of selected exotic and native aquatic plant communities on water temperature and dissolved oxygen," Information Exchange Bulletin A-93-2, Aquatic Plant Control Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Keddy, P. A. (1983). "Shoreline vegetation in Axe Lake, Ontario: Effects of exposure on zonation patterns," *Ecology* 64, 331-344.
- Kentula, M. E., Brooks, R. P., Gwin, S. E., Holland, C. C., Sherman, A. D., Sifneos, J. C. (1993). *An approach to improving decision making in wetland restoration and creation*. A. J. Hairston, ed., U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.
- Killgore, K. J., Morgan, R. P., and Rybicki, N. B. (1989). "Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River," *North American Journal of Fisheries Management* 9, 101-111.
- Kollar, S. A. (1985). "SAV reestablishment Results - Upper Chesapeake Bay. Coastal Zone, Vol. 1. *Proceedings 4th Symposium on Coastal and Ocean Management*. O. T. Magoon, H. Converse, D. Miner, D. Clark, and L. T. Tobin, ed.
- \_\_\_\_\_. (1988). "The results of submersed plant transplant activities and water quality in upper Chesapeake Bay, 1986-1987," Final Report to Coastal Resources Division, Tidewater Administration, Maryland Department of Natural Resources.
- Korschgen, C. E., and Green, W. L. (1988). "American wild celery (*Vallisneria spiralis*): Ecological considerations for restoration," Fish and Wildlife Technical Report 19, U.S. Department of the Interior, Fish and Wildlife Service.

- Kufel, L., and Ozimek, T. (1994). "Can Chara control phosphorus cycling in Lake Luknojno (Poland)?" *Hydrobiologia* 275/276, 277-283.
- Kunii, H. (1982). "Life cycle and growth of *Potamogeton crispus* L. in a shallow pond," *Ojaga-ike. Bot. Mag. Tokyo* 95, 109-124.
- Langeland, K. A. (1990). "Hydrilla: A continuing problem in Florida waters," Circular No. 884, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.
- Madsen, J. D. (1991). "Resource allocation at the individual plant level," *Aquatic Botany* 41, 67-86.
- Madsen, J. D., Eichler, L. W., Sutherland, J. W., Bloomfield, J. A., Smart, R. M. and Boylen, C. W. (1993). "Submersed littoral vegetation distribution: Field quantification and experimental analysis of sediment types from Onondaga Lake, New York," Technical Report A-93-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Madsen, J. D., Sutherland, J. W., Bloomfield, J. A., Eichler L. W., and Boylen, C. W. (1995). "Salinity and sediment effects on the growth of six aquatic macrophytes for potential revegetation of Onondaga Lake, New York," submitted to *Wetlands*.
- May, R. M. (1977). "Thresholds and breakpoints in ecosystems with a multiplicity of stable states," *Nature* 269, 471-477.
- McCreary, N. J., McFarland, D. G., Barko, J. W. (1991). "Effects of sediment nitrogen availability and plant density on interactions between the growth of *Hydrilla verticillata* and *Potamogeton americanus*," Technical Report A-91-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Nichols, S. A. (1992). "Depth, substrate, and turbidity relationship of some Wisconsin lake plants," *Trans. Wis. Acad. Sci. Arts Lett.* 80, 97-118.
- Olesen, B., and Sand-Jensen, K. (1994). "Patch dynamics of eelgrass *Zostera marina*," *Mar. Ecol. Prog. Ser.* 106, 147-156.
- Pieterse, A. H. (1981). "*Hydrilla verticillata* - a review," *Abstracts on Tropical Agriculture* 7, 9-34.
- Prescott, G. W. (1978). *Freshwater algae*. Wm. C. Brown Company Publishers, Dubuque, IA.
- Rorslett, B. (1985). "Environmental factors and aquatic macrophyte response in regulated lakes - a statistical approach," *Aquat. Bot.* 19, 199-220.

- Scheffer, M. (1990). "Multiplicity of stable states in freshwater systems," *Hydrobiologia* 200/201, 475-486.
- Scheffer, M., Hosper, S. H., Meijer, M. L., Moss, B., and Jeppesen, E. (1993). "Alternative equilibria in shallow lakes," *Trends in Ecology and Evolution* 8, 275-279.
- Schramm, J. L., Jr., and Jirka, K. J. (1989). "Effects of aquatic macrophytes on benthic macroinvertebrates in two Florida lakes," *J. of Freshwater Ecology* 5, 1-12.
- Schriver, P., Bogestrand, J., Jeppesen, E., and Sondergaard, M. (1995). "Impact of submerged macrophytes on fish-zooplankton-phytoplankton interactions: Large-scale enclosure experiments in a shallow eutrophic lake," *Freshwater Biol.* 33, 255-270.
- Sheldon, S. P. (1986). "The effects of short-term disturbance on a freshwater macrophyte community," *J. Freshwater Ecol.* 3, 309-317.
- Smart, R. M., and Barko, J. W. (1985). "Laboratory culture of submersed freshwater macrophytes on natural sediments," *Aquatic Botany* 21, 251-263.
- Smart, R. M., Barko, J. W., and McFarland, D. G. (1994). "Competition between *Hydrilla verticillata* and *Vallisneria americana* under different environmental conditions," Technical Report A-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Smart, R. M., and Dorman, J. D. (1993). "Latitudinal differences in growth strategy of a submersed aquatic plant: Ecotypic differentiation in *Vallisneria americana*?" *Bulletin of the Ecological Society of America, Suppl.* 74, 439.
- Smart, R. M., and Doyle, R. D. (1995). "Ecological theory and management of submersed aquatic plant communities," Information Exchange Bulletin A-95-3, Aquatic Plant Control Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Spence, D. H. N. (1982). "The zonation of plants in freshwater lakes," *Adv. in Ecological Research* 12, 37-125.
- Stearns, S. C. (1977). "The evolution of life history traits: A critique of the theory and a review of the data," *Annu. Rev. Ecol. Syst.* 8, 145-171.
- Tennessee Valley Authority. (1992). "Master plan: Main report Gunter'sville Reservoir aquatic plant management," Joint Agency Gunter'sville Project TVA/WR 92/21.



- Titus, J. E. (1993). "Submersed macrophyte vegetation and distribution within lakes: Line transect sampling," *Lake and Reservoir Management* 7, 155-164.
- Titus, J. E., and Adams, M. S. (1979). "Comparative carbohydrate storage and utilization patterns in the submerged macrophytes *Myriophyllum spicatum* and *Vallisneria americana*," *Am. Midl. Not.* 102, 263-272.
- Titus, J. E., and Hoover, D. T. (1991). "Towards predicting reproductive success in submersed freshwater angiosperms," *Aquatic Botany* 41, 111-136.
- van der Valk, A. G. (1981). "Succession in wetlands: A Gleasonian approach," *Ecology* 62, 688-696.
- Webb, D. H. (1993). "Aquatic macrophyte assessment - Joint Agency Guntersville Project." *Proceedings, 27th Annual Meeting, Aquatic Plant Control Research Program*. Miscellaneous Paper A-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 33-38.

# Appendix A

## Line-Intercept Transect Method

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The following line-intercept method is used by John D. Madsen.

A transect line with markings every 1 m is prepared. A 1/4- or 3/8-in. nylon braided rope is used, preferably in a bright color such as yellow. The markings can either be permanent marker or flagging. Fluorescent flagging is preferred, often using an alternate color for the 5- and 10-m intervals to help in keeping track of where one is on the transect. The transect can either be a set length (e.g., 100 m) or the length between permanent markers in the case of permanent transects.

Data are recorded on data sheets such as that appended. For each 1-m interval, all species or target species are marked if they are present (1) or absent (0) between the two marks, below the line; in other words, if the species crosses or intercepts the vertical plane made by the line segment. Additional data, such as water depth or sediment type, can also be recorded for analysis of correspondence between species occurrence and environmental conditions. For a given study, more than one transect should be utilized. If the study involves a treatment effect versus reference, 400 intervals is recommended (preferably as four 100-m transects) for each plot. The more transects or intervals used, the greater the statistical power in subsequent data analyses. For quantification of plants in a lake, stratified-random deployment of transects is recommended around the perimeter of the lake, and generally deployed perpendicular to shore. However, transect methods can be adapted for many study purposes and objectives.

Data analysis can be made as easily as counting the number of intervals species present and dividing by the total number of intervals examined. This gives a frequency of occurrence. For large numbers of intervals, this provides a rough approximation of percent cover. Before and after analyses or comparisons between transects for a given species can be made using a two-by-two or chi-square analysis using the actual numbers of intervals with and without the species. For statistical analyses, the actual numbers rather than frequencies should be used. For instance, a given study of the effectiveness of herbicide X was set up in one plot in which four 100-m transects were used as a treatment plot and a similar setup for a reference plot. Transect analysis

indicated that pretreatment transect counts found 320 intervals with the target species and 80 without. Six weeks after treatment, the analysis noted 200 intervals with the target species and 200 without. The two-by-two analysis for the treatment plot would look like this:

	Pretreatment	Posttreatment	Totals
Intervals with target species	320	80	400
Intervals without target species	200	200	400
Total	520	280	

The chi-square analysis, using the actual interval counts, indicated a significant reduction in the presence (or frequency or cover) of the target species, using the Pearson's Chi-square test ( $p < 0.001$ ).

Data entry for the computer can be done by using a "1" for intervals with species present and a "0" for intervals in which species are absent and then utilizing the appropriate statistical package. Data entry will also facilitate calculation of indices of species richness, presence/frequency of classes of plants (dicots, monocots, native, and exotic), and can also be used to construct maps of vegetation if transect locations are known.

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## Bibliography

- Madsen, J. D., Dick, G. O., Honnell, D., Shearer, J., and Smart, R. M. (1994). "Ecological assessment of Kirk Pond," Miscellaneous Report A-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Madsen, J. D., Eichler, L. W., Sutherland, J. W., Bloomfield, J. A., Smart, R. M., and Boylen, C. W. (1993). "Submersed littoral vegetation distribution: Field quantification and experimental analysis of sediment types from Onondaga Lake, New York," Technical Report A-93-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Madsen, J. D., Sutherland, J. W., Bloomfield, J. A., Eichler L. W., and Boylen, C. W. (1991). "The decline of native vegetation under dense Eurasian watermilfoil canopies," *Journal of Aquatic Plant Management* 29, 94-99.

DATE		WATER BODY		SITE	
TRANSECT		TRANSECT SHEET		OBSERVER	

### TRANSECT DATA

[illegible]

**NOTES:**

# REPORT DOCUMENTATION PAGE

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<b>14. SUBJECT TERMS</b> Aquatic plant establishment Ecosystem restoration Habitat enhancement			<table border="1"> <tr> <td>Hydrilla</td> <td>Vallisneria</td> </tr> <tr> <td>Native macrophytes</td> <td></td> </tr> <tr> <td>Revegetation</td> <td></td> </tr> </table>		Hydrilla	Vallisneria	Native macrophytes		Revegetation	
Hydrilla	Vallisneria									
Native macrophytes										
Revegetation										
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